LOK-TEST for timing of safe and early loading operations,
Canadian Experience

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Civil-2025 Conference
3rd International Summit on Civil, Structural and Environmental Engineering,
Frankfurt, Germany,
July 21-23, 2025

Collapse during Formwork Removal

- Multi-story building collapse in Boston, USA, 1971
- 4 construction workers died.
- Standard cylinders tested had passed the requirement.
- Subsequent investigation showed the in-place strength to be 50% of the cylinder strength at the time of formwork removal.

Cooling Tower Collapse, April 1978
Willow Island, W.Va., USA

- Failure due to insufficient strength to support next “lift”
- 51 deaths
- Timing of next lift was determined by cylinders

LOK-TEST was subsequently used for in-place strength before moving to the next lift, 24 inserts in each lift.

Courtesy of NIST

Beam collapse, Moscow

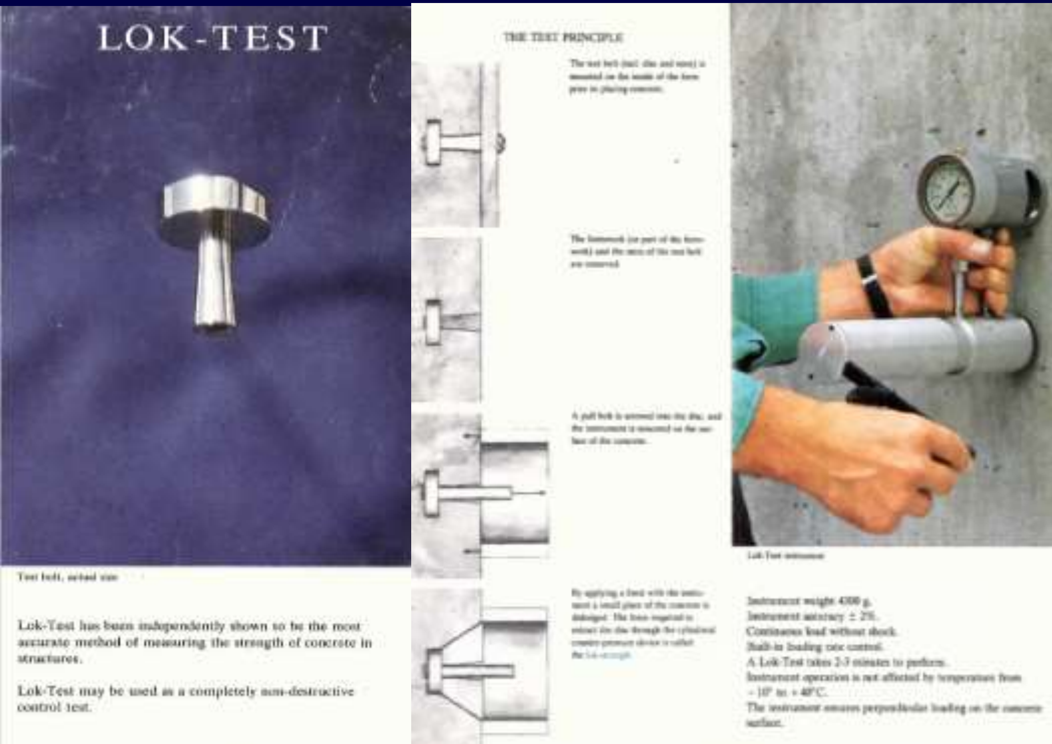
- Beam collapse in a new Russian grocery store after opening 1979,
- 7 people killed
- Lab cylinders had passed the required strength 40 MPa
- Capo-Test showed 7-9 MPa strength in-place after the collapse

Rana Plaza collapse, Bangladesh

RANA PLAZA COLLAPSE, textile factory, Dhaka, Bangladesh, 2016

Another 3 story´s were build on top of the existing factory. Cracking in the walls happened prior to the collapse killing at 1,132 people and injured more than 2,500

- Lab testing unknown.
- Strength testing of the concrete quality months before collapse was made by rebound hammer, UPV and cores



LOK-TEST

Test bolt, actual size

Lok-Test has been independently shown to be the most accurate method of measuring the strength of concrete in structures.

Lok-Test may be used as a completely non-destructive control test.

THE TEST PRINCIPLE

Lok-Test instrument

Instrument weight 4300 g.
Instrument accuracy ± 2%.
Continuous load without shock.
Built-in loading rate control.
A Lok-Test takes 2-3 minutes to perform.
Instrument operation is not affected by temperature from −10° to +40°C.
The instrument ensures perpendicular loading on the concrete surface.

LOK-TEST

Peter Kierkegaard-Hansen
US patent 3541845, 1970

Pamphlet

- Sent out to Danish Embassies in 1972
- In Vancouver the Ambassador informed Civ.Eng. Kaj Holbeck of the new test system, and Mr.John A. Bickley, P.Eng., Trow Group, Toronto, Canada, was notified subsequently by Mr. Holbeck, his personal friend.
- John boarded the next plane to Copenhagen to meet Profesor Herbert Krenchel, DTU and acquire the LOK-TEST, "The Holy Grail of Testing" as he later called it.

The complete Lok-Test "Laboratory in a Briefcase"

LOK-TEST LTD.

Legend:

1. Research by Lok-Test ApS
2. Research by Technical University, Copenhagen
3. Research by Road and Railway Departments
4. Research by Danish Engineering Academy
5. Recommended conversion equation:

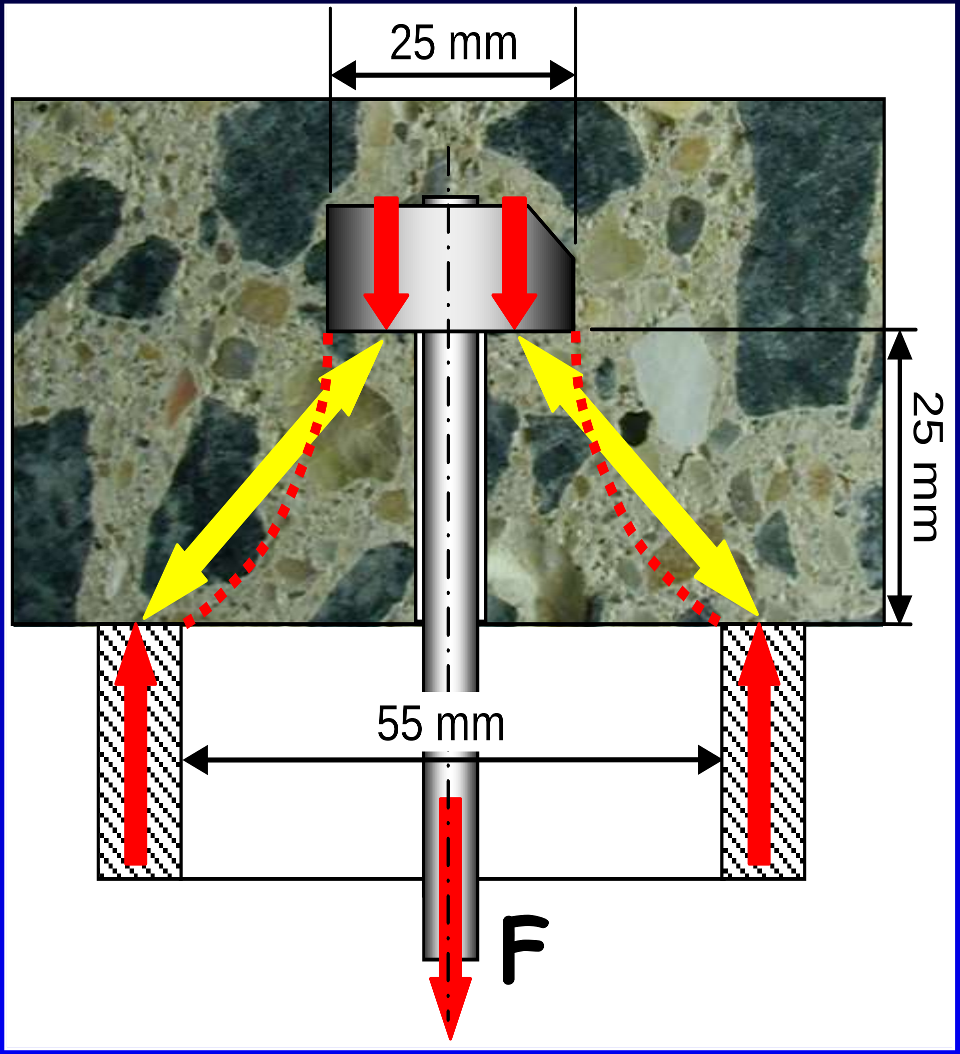
$$L\ (kN) = 5 + 0.8\ f_c\ (MPa)$$

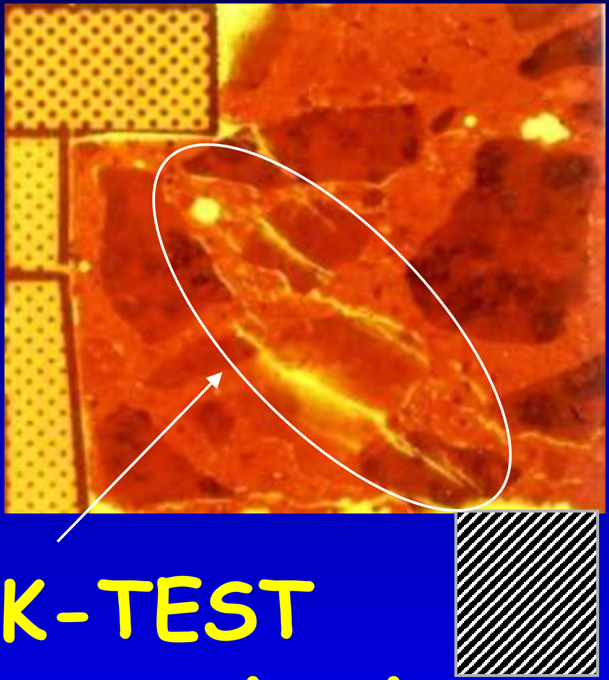
NON-DESTRUCTIVE TESTING

For in-situ control: Load to the force representing the required strength. If the concrete in the structure withstands this force, unload and remove the instrument. The concrete will then be undamaged.

First patent 1964

LOK-TEST failure mechanism





LOK-TEST compression in the "strut",

The pullout force F is directly related to compressive strength (uniaxial) for the geometrical dimensions stated

Canadian LOK-TEST pullout standard

A23.2-15C

Evaluation of concrete strength in place using the pullout test

1 Scope

This Test Method describes the evaluation of the in-place hardened concrete compressive strength of a structural element using the pullout test. Pullout strength is obtained through the measurement of the force required to pull a metal insert, previously inserted in a mass of fresh concrete. The force measured is correlated to an equivalent compressive strength of the concrete on standard cylinders, through a correlation curve. This Test Method is applicable to concrete with a nominal maximum aggregate size of 40 mm or less.

2 Reference publications

In addition to the references in CSA A23.1, this Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1-14
Concrete materials and methods of concrete construction

A23.2-1C-14
Sampling plastic concrete

A23.2-3C-14
Making and curing concrete compression and flexural test specimens

A23.2-9C-14
Compressive strength of cylindrical concrete specimens

A23.2-1D-14
Moulds for forming vertical concrete test cylinders

ACI (American Concrete Institute)

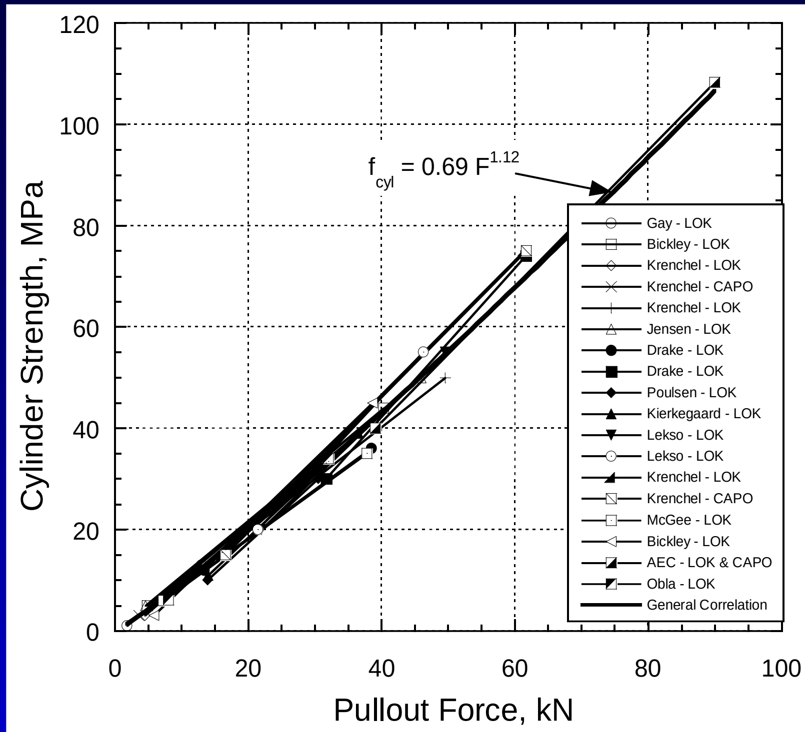
228.1R (14)-03
In-Place Methods to Estimate Concrete Strength

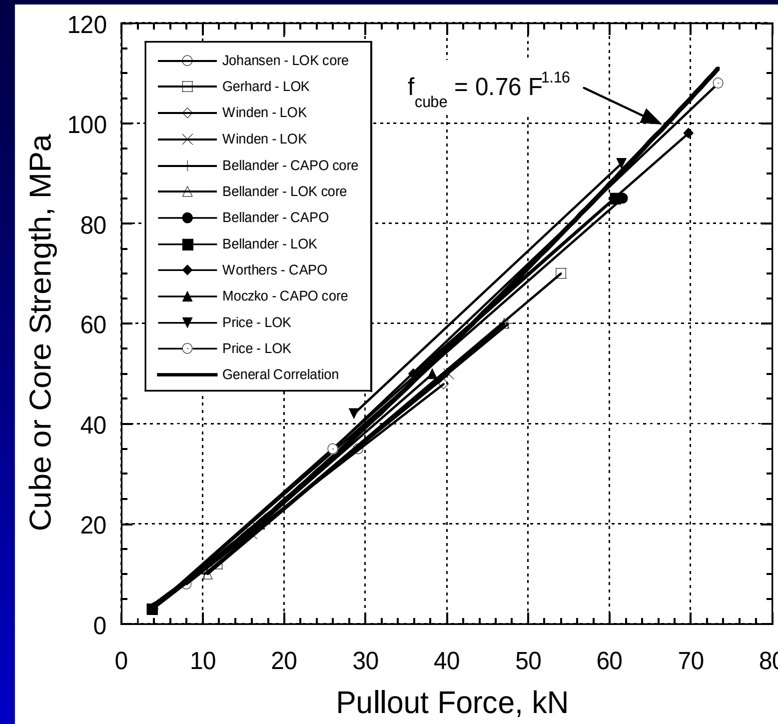
ASTM International (American Society for Testing and Materials)

C900-13
Standard Test Method for Pullout Strength of Hardened Concrete

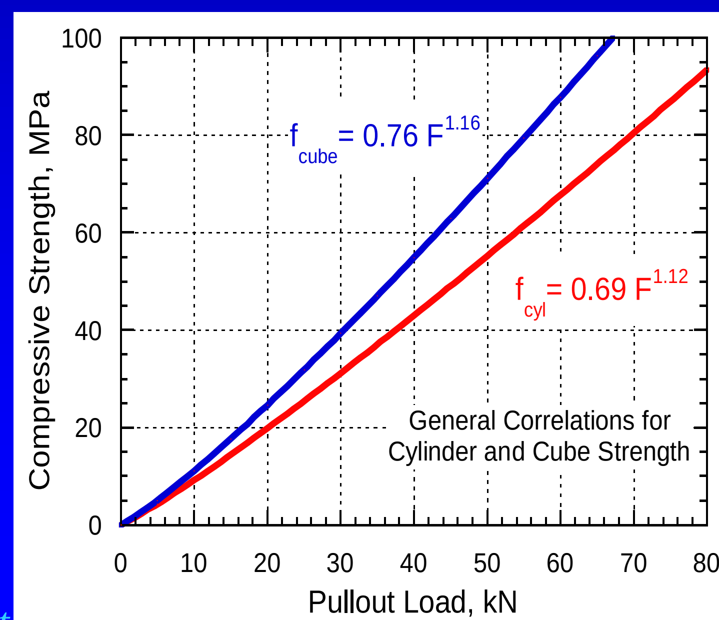
E4-13
Standard Practices for Force Verification of Testing Machines

E74-13a
Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines



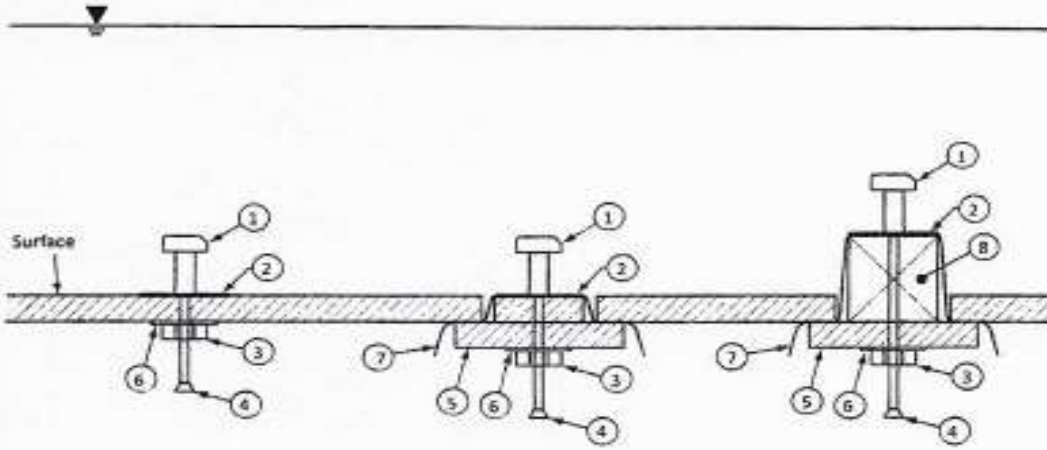


Robust, general correlation



GI

Canadian Standard insert intallment



Legend:

(1)	Insert	(5)	Wood block assembly
(2)	Smooth steel plate (no perforations)	(6)	Lock washer
(3)	Nut	(7)	Plastic sheet
(4)	Bolt	(8)	Wood block assembly

Figure 3
Typical insert installations for formed surfaces
(See Clauses 7.1.1.1, 7.1.2, and 7.1.3.)

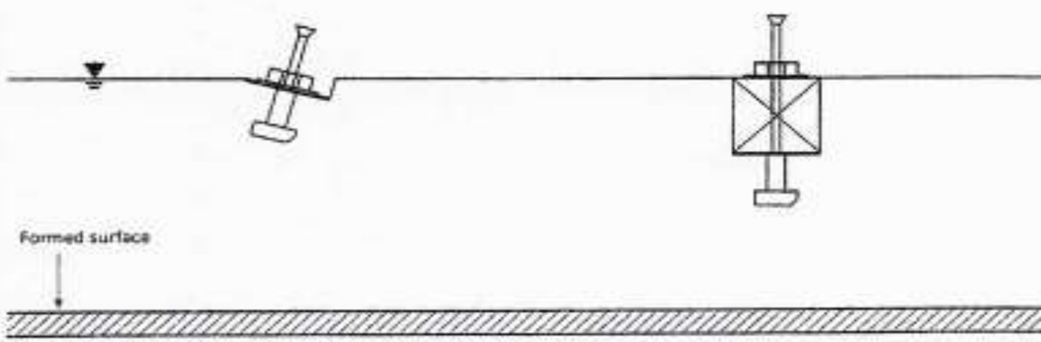
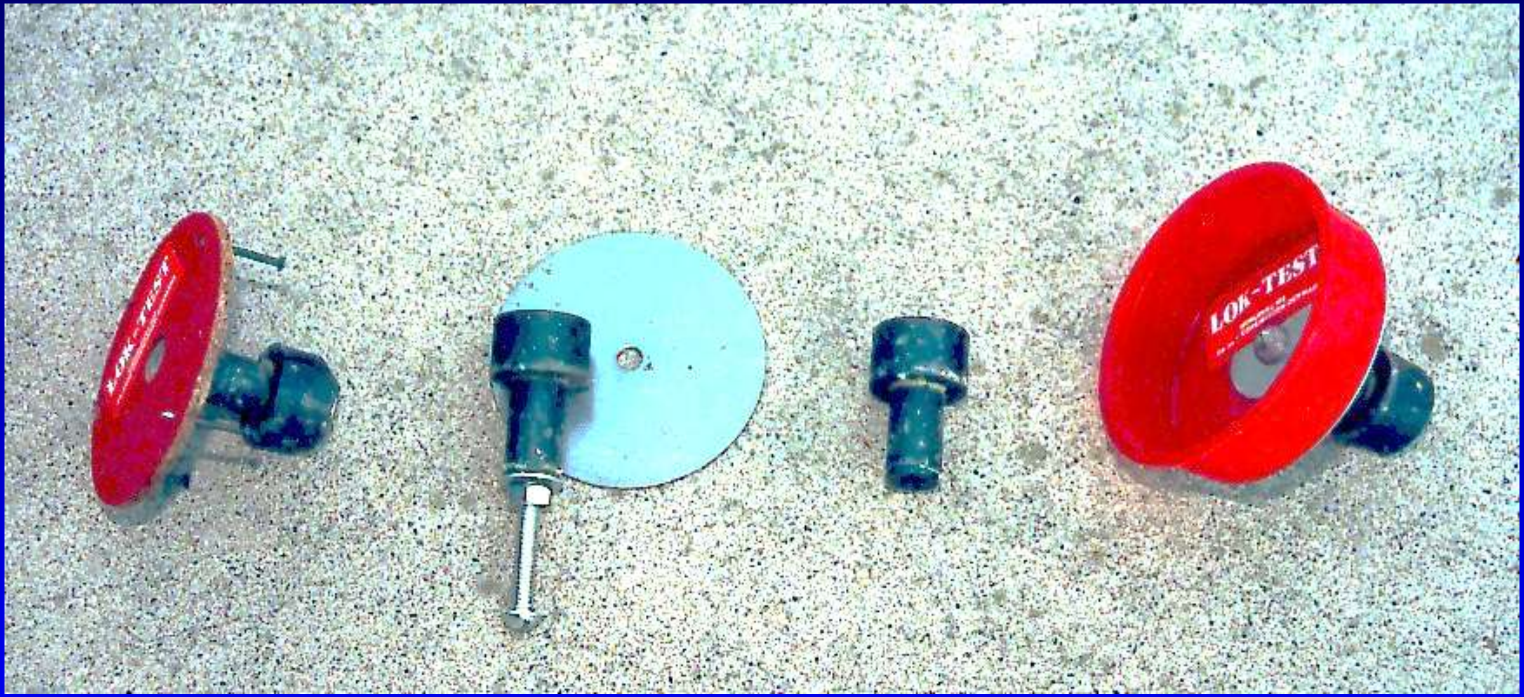


Figure 4
Typical insert installations for unformed surfaces
(See Clause 7.1.1.1.)

Lok-Test inserts

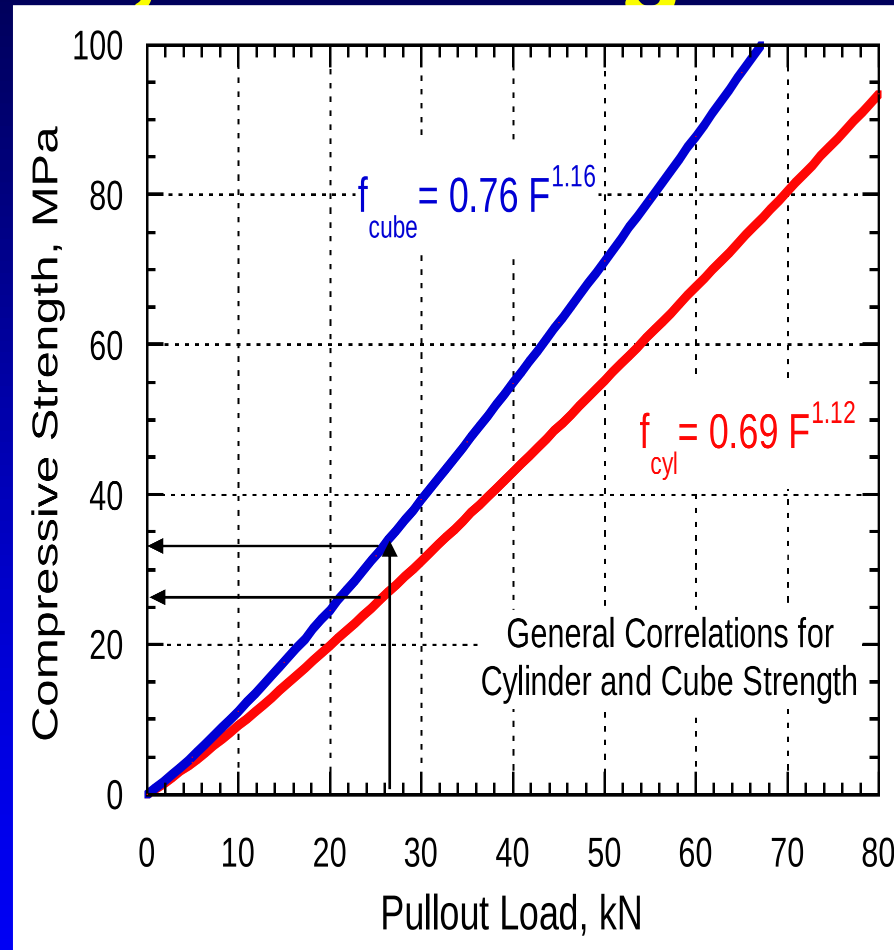
re-usable



L-41	L-43	L-46	L-50
Nailing to wooden formwork	Top surface or through 7 mm hole in formwork	Insert only	Floating in top surface or 40 mm deep installment

LOK-TEST

Pullout force F in kN, “H” for Highest



F = 27.4 kN ⟶ f_{cyl}=28.1 MPa or f_{cube}=35.4 MPa

(Cubes 25% higher than cylinder strength)

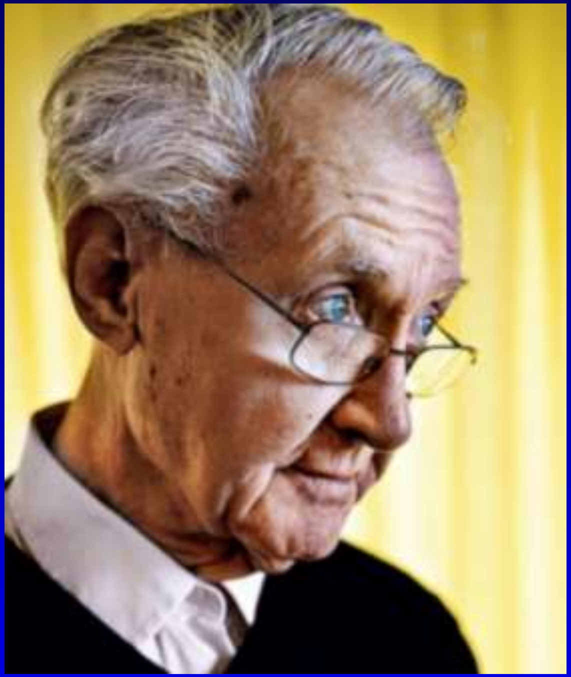
)

GI

LOK-TEST Essentials

- Compressive strength in-place, accurately
- LOK-TEST inserts to be installed before or during casting
- For speeding up in-situ cast building job, safely
- Durability of the critical cover layer protecting the reinforcement e.g. in the splash zone or buttom of high-way columns
- Portable, quick (3-5 minutes test), easy to operate, carried out simple and inexpensive.
- Robust, straight line general relationship between pullout force and uniaxial compressive strength for all normal mixes (max aggregate size <40 mm), one to standard cylinders and one to cubes.
- Accuracy ±0.5 MPa and Precision within 2 MPa for an average of two tests, 1.5 MPa for four

Three of the Lighthouses in Pullout Testing



Professor, dr.techn.
Herbert Krenchel
Deptm. of Structural Engineering, DTU, Denmark

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TROW, Canada

Professor
Emeritus of C.Eng.
Ervin Poulsen
Engineering Academy, DIA-B, Denmark

Canadian experience using LOK-TEST for safe and early loading operations, reported 2009 John A. Bickley, Doctor of Science (Honoris Causa), P.Eng., FICE, FCSCE

A Brief History of Pullout Testing; With Particular Reference to Canada

A Personal Journey

By John A Bickley, P.Eng.

Introduction

From the thirties to the seventies a number of researchers worked on the development of the pullout test as an in-situ method of determining the strength of concrete in a structure. Research in Russia in the years 1934-1938 by Volf, Charckov and Gershberg was reported in 1938 by Skramtajev. In the sixties and seventies Richards in the US and Malhotra in Canada carried out experiments with prototype equipment and initiated the drafting of an ASTM test procedure. During this period Kierkegaard-Hansen in Denmark established the relative dimensions of the pullout and pullout test equipment that resulted in a straight line correlation between pullout force and compressive strength.

A field research programme funded by the National Research Council of Canada showed that the pullout test was an accurate way of determining the compressive strength of concrete in-situ. However the 3 inch diameter pullout used by Richards and Malhotra resulted in large, cumbersome test equipment impractical for site use. In Denmark, using the relationships

Source: John A. Bickley, P.Eng., :"A Brief History of Pullout Testing; With Particular Reference to Canada", ACI International Conference on Non-Destructive Testing, Seville, Spain, October 15th, 2009

Abstract

How to Build Faster for Less - The Role of In-Place Testing in Fast Track Construction

John A. Bickley, P.Eng.
President, John A. Bickley Associates Ltd., Toronto, Ontario, Canada

Kal R. Hindo, P.E.
Sr. Vice President, NTH Consultants Ltd., Farmington Hills, Michigan, U.S.A.

The economic needs of today dictate that many projects shall be built to a fast-track schedule. Recent developments in cementitious materials and admixtures have provided unlimited scope for the formulation of concrete mixes. Early age and later age high strength requirements can be met with the same mix. The safe removal of formwork from structural components can be accomplished at ages less than 24 hours. Post-tensioning, re-shoring, and curing in cold weather can be controlled to optimum economic cycles.

These economic benefits can be achieved by the use of selected in-place testing procedures which allow a fast track approach with safety.

Using a financial analysis, this paper demonstrates how the authors' approach can form part of a logical plan which facilitates speed of construction, ensures high quality, and results in significant cost savings.

Source: Bickley, J.A. & Hindo, K.R.: "How to Build Faster for Less – The Role of In-Place Testing in Fast Track Construction", ACI Spring Convention, March 20, 1994

Strength for Formwork Removal

Scotia Plaza – Toronto, Canada.

- SAFE and EARLY stripping of forms using LOK-TEST for estimating in-place strength has been done on +600 major structures
- Essence: Earnings due to speeding up construction schedule reported to be about 0.7 to 1.5 M Dollars

Source: Bickley, J.A.: "How to Build Faster for Less – The Role of In-Place Testing in Fast Track Construction", ACI, Spring Convention, San Francisco, 1994

- Attach insert assembly to form
- Place concrete
- Test from below

LOK-TEST for early and safe loading operation

10 inserts tested in less than 1 hour (15 installed)

Shown is Principal Mr. Sal Fasullo, C.E.T., Davroc & Associates Ltd., Canada, performing the LOK-TEST, 5 minutes per test, saved values in the instrument: Peak Load, Time of Testing & Date of Testing

- In a 100 m^3 slab pour 10 to 15 LOK inserts are installed equally distributed on the bottom of the slab through prepared port holes in the flying form systems.
- If tested from the top using floating LOK inserts, experience has shown a ~10% lower strength than at the bottom due to better compaction and curing at the bottom
- At time of testing, e.g. evaluated by maturity, a couple of inserts are tested, and if meeting the expectations, the remaining inserts are tested. Ten inserts can be tested in about one hour.
- The usual procedure is to load the LOK disc exactly to failure, record the kN pullout force and convert it to cylinder compressive strength in MPa by means of pre-established relationship and/or the general correlation.

- The average $\overline{X}$ and the standard deviation σ are calculated as well as the "Minimum in-place strength" as $$f_{c\,min} = \overline{X} - k \cdot \sigma$$
  "k" being the 10% fractile in the T-distribution (for e.g. number of tests n = 10 the "k" factor is 1.67, for n = 15, "k" is 1.58)
- The Criterion / Decision:
  Strip if $f_{c\,min} > 75\%$ of the f´c, the specified strength

Example:
15 LOK inserts installed in a 100 m^3 slab pour (consisting of 20 batches)
Specified strength f´c = 30 MPa,
Minimum strength for form removal 0.75 f´c = 22.5 MPa
Measured LOK-TEST in MPa on 10 of the inserts: 27.5, 25.0, 22.5, 25.0, 22.5, 24.0, 25.5, 28.5, 25.0, 30.0 giving $f_{c\,min} = \overline{X} - k\,\sigma = 25.6\ MPa - 1.67 \cdot 2.3\ MPa = 21.8$ MPa. Alternatives to reach the required 22.5 MPa either make 2-3 more tests or wait 1-2 hours for additional curing time – and then test a few inserts more.

Source: Bickley, J.A.: "The Evaluation and Acceptance of Concrete by In-Place Testing", SP 82-6, ACI

Ontario Projects reported in 1981

	Site	Structure	Specified 28 Day Strength MPa	Specified form removal strength, MPa	Number of Pull-out Tests made on the structure
1	Ashbridges day	205 m Chimney	27.6	6.9	326
2	2900 Battleford	15 Storey Apartment	20.7	13.8	719
3	Continental Bank	33 Storey Apartment	27.6	20.7	700
4	Islington Ave. Bridge	Segmental Bridge	41.4	10.3 (stressing)	45
5	Warden and Passmore	20 Storey Apartment	20.7	155 mean 14.5 min	596
6	Dundas and Tomken	15 Storey Apartment	N/A	15.5 mean 13.8 min3	316
7	Obelisk phase III	24 Storey Apartment	27.6	Not known	99
8	Consumers Gas, Hilton	Silo Base	27.6	20.7	15
9	Red Hill Creek	Trunk Sewer	276	6.9	30
10	Lockwood Park	12 Storey Office Building	20 25 30	14.5 13.8	368
11	110 Bloor Steet	21 Storey Office Building	207	14.5	348
12	York-Durham Street	Sewer Pipe Cradles	25	20	63
13	Highway 427	Bridge Column	N/A	N/A	240
14	Senior Citizen Phillmore Building	15 Storey Apartment	20.7	13.8	301
15	Shipp Centre	20 Storey Office Building	24.1	17.2	88
16	Town of Vaugham	Trunk Sewer	N/A	Not known	19
17	Trinity Square	Office Building	27.6	20.7	28
18	Yukon	Trunk Sewer	Not known	Not known	---*

Source: Bickley, J.A. & Fasullo, S.:"Analysis of Pull-Out test data from construction sites", Transportation Rearch Board, Sixtieth Annual Meeting, January 12th, 1981, Washington D.C., USA

Savings to Owners, Fast Track Construction Examples

	20 Storey Office Building	15 Storey Utility Headquarters	30 Storey Office Headquarters	Twin Apartment Towers, 30 and 31 Storeys	14 Storey [5] Office Building	3 Storey Computer Center	9 Storey Condos
SAVINGS	(All Numbers are $/1000)						
Interest Charges	600	1750	188	NC	NC	533	43
Earlier Rental	200	NC	25	NC	NC	466	40
Formwork	120	25[4]	NC	75	NC	NC	NC
Re-Shoring	NC	NC	NC	NC	NC	NC	NC
Winter Heating	NC	NC	114	(0.3/Pour/Day)	NC	NC	NC
f'_c at 91 days	NA	50	38	62	23	NA	NA
Design	120	NA	NA	NA	NA	NA	NA
Overhead	NC	NC	20	NC	NC	NC	NC
Sub-Total	1040	1825	385	137	NC	999	83
COSTS							
Concrete	20[1]	320	152	56	93	20	0
Testing	15[2]	38	24	10	14	10	4
Sub-Total	35	358	176	66	107	30	4
NET SAVING	1005[3]	1467	209	71	NC	969	79

Source: Bickley, J.A. & Hindo, K.R.: "How to Build Faster for Less – The Role of In-Place Testing in Fast Track Construction", ACI Spring Convention, March 20, 1994

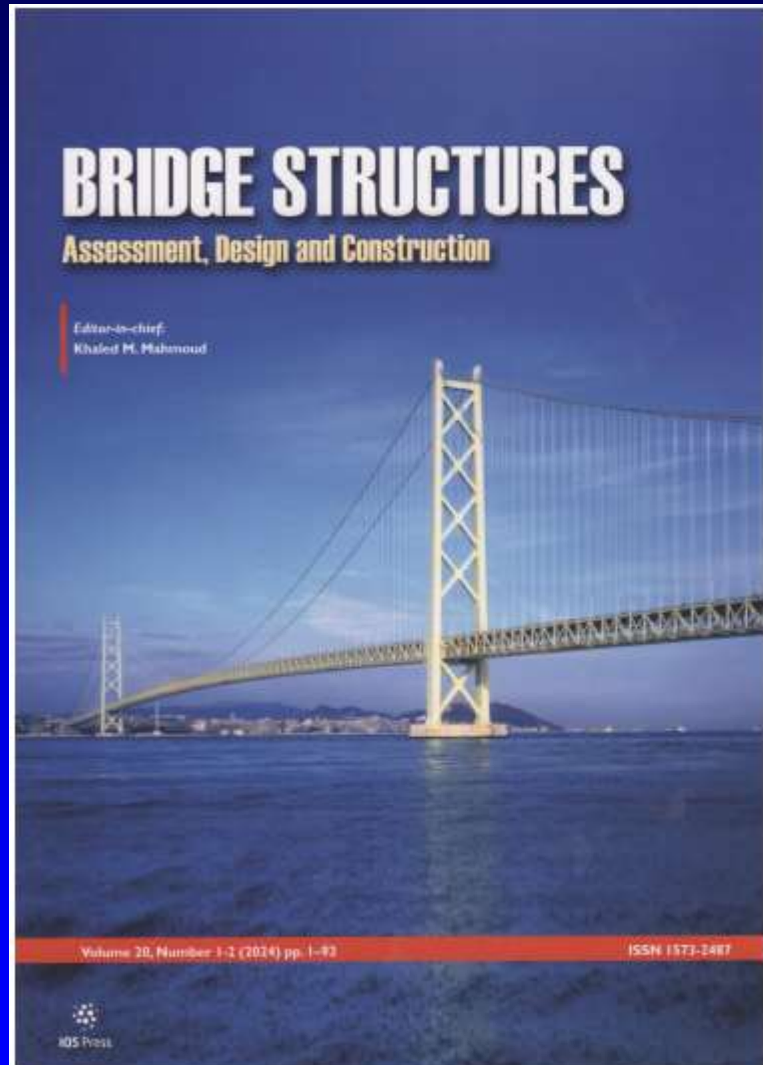
- Optimized concrete mixes are used, e.g. the "Super-Stripper", allowing forms to be removed safely as quickly as after 1.5 actual days, even in cold winter conditions. On the other hand, in the substructure, strength is not needed that quickly. Here e.g., fly ash, slag cement, or other supplementary materials is used in the mixes, reducing the costs
- On projects in Canada the building officials allowed the elimination of the usual standard cylinder test, only relying on LOK-TEST for in-place strength.
- Benchmarking 50 years of the system is stated in the recent paper (slide 26) by Mr. Claus Germann Petersen: "LOK-TEST and CAPO-TEST pullout for *in-situ* concrete strength", BRIDGE STRUCTURES, DOI:10.3233 / BRS-240220, IOS Press, ISSN 1573-2487©2024, shown slide 24

Canada success factors:

Making Money by combining selected mixes and testing using LOK-TEST in-situ, simple, fast, very economical and reliable.

John A. Bickley: LOK-TEST is "The Holy Grail of Testing"

Detailed information, right-click



Cover layer quality
Second main application

Professor Ervin Poulsen, Denmark:

"The cover layer is the critical part of the structure in terms of durability, the interior only needs to be strong enough to withstand the forces applied"

Professor
Emeritus of C.Eng.
Ervin Poulsen
Engineering Academy,
DIA-B, Denmark

Durability & Uniformity using LOK-TEST

- **Production testing** at the Great Belt Link, Denmark, Case 13.1, p.34 in the publication on previous slide 26
- **Service life** of bridge pier, Great Belt Link, Denmark, Case 13.2, p.37 in the publication on previous slide 26
- **Curing of the cover layer** evaluated by pullout and conductivity, Case 13.3, p. 38 in the publication on previous slide 26

Thank you

Questions?

www.germanninstruments.com
www.ndtitans.com